Appendix C

FYR Risk Evaluation

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C1.0 Introduction

This appendix presents the methodology for reviewing and evaluating changes to chemical and radiological risk assessment parameters that took effect during this FYR period and details the results of the risk evaluation. The methodology used for this evaluation is based on the methodology used for the comprehensive risk assessment (CRA) completed in 2006. The CRA included a human health and ecological risk assessment for the COU and POU; a separate risk assessment was completed for OU3 (DOE 1997). A summary of the CRA may be found in the Third FYR report (DOE 2012) and the complete CRA is found as an appendix to the RI/FS Report (DOE 2006).

In accordance with CERCLA, this FYR must provide an evaluation of changes to risk factors for the COU to determine if these changes have an impact to the risks presented by residual contamination left on site. The conclusions of this evaluation are then used to determine if the remedy remains protective.

Although this FYR risk evaluation is limited to risks posed by residual contamination within the COU, a separate review of the impacts of risk assessment factors was conducted for the POU and OU3. The purpose of this separate review was to determine if the UU/UE designation is still valid at both OUs. The POU and OU3 were both deleted from the National Priorities List (NPL) in 2007 because they posed no significant threat to public health or the environment (add FR reference).

C2.0 Central and Peripheral Operable Units

In the RI/FS Report (DOE 2006), the nature and extent of residual contamination in soil and sediment were evaluated after completion of the RFCA accelerated actions. Each nature and extent of contamination evaluation identified analytes of interest (AOIs). AOIs are chemicals that have been detected at concentrations that may contribute to the risk to future receptors. The evaluation studied the extent of sitewide contaminants and evaluated which chemicals remained after the completed accelerated actions. The soil AOIs identified in the RI/FS Report are presented in Table C-1.

In 2006, a comprehensive risk assessment was completed for the Rocky Flats Site to quantify the risk of residual contamination remaining after accelerated cleanup actions at the site (DOE 2006). The CRA was conducted in accordance with the EPA- and CDPHE-approved *Comprehensive Risk Assessment Work Plan and Methodology* (DOE 2005c). Calculations and conclusions in the CRA were based on post-remediation data; that is, data collected after the completion of all RFCA accelerated actions. To facilitate the CRA, the Site was divided into the twelve exposure units (EUs) shown in Figure C-1. The basic methodology for conducting human health risk assessments, as described in the *Risk Assessment Guidance for Superfund* (EPA 1989), has not changed since the CRA was completed.

C2.1 Risk Definitions

This section presents the definitions of key risk terms used throughout this appendix.

95 percent upper confidence limit (95UCL): This is statistical upper bound estimate of the mean for a set of samples and is a conservative measure of the average concentration. As a general rule, EPA recommends use of the 95UCL as the exposure point concentration for soils at a site (EPA 2002).

Cancer risk: Presents the added probability of an individual or population of developing cancer during a lifetime as a result of exposure to site contaminants. The acceptable risk range for CERCLA sites is an added risk of less than 1 in 1,000,000 (1×10^{-6}) to a maximum of 1 in 10,000 (1×10^{-4}).

Dose conversion factor: The dose to the human body associated with an exposure to a radionuclide (usually presented in mrem/pCi or (mrem/yr)/(pCi/g)).

Hazard quotient: The ratio of the exposure level of a single substance to an acceptable noncarcinogenic toxicity value. If multiple substances are present, hazard quotients are summed in a hazard index. For CERCLA sites, the maximum acceptable hazard index is 1.0.

Maximum detected concentration (MDC): Maximum concentration detected in any soil sample a given constituent and exposure unit.

Slope Factor: An estimate of the risk of developing cancer associated with exposure to a carcinogenic or potentially carcinogenic substance.

Table C-1. Soil AOIs identified in the RI/FS

Surface Soil (0–0.5 ft)	Subsurface Soil (0.5–8 ft)	Subsurface Soil (>8 ft)
Radionuclides		
Americium-241 Plutonium-239/240 Uranium-233/234 Uranium-235 Uranium-238	Americium-241 Plutonium-239/240 Uranium-235 Uranium-238	Plutonium-239/240
Metals		
Aluminum Arsenic Chromium (Total) Vanadium	Chromium (Total) Lead	
Volatile Organic Compounds (VOCs)		
	Tetrachloroethene	1,1,2,2-Tetrachloroethane CarbonTetrachloride Chloroform Methylene Chloride Tetrachloroethene Trichloroethene
Semivolatile Organic Compounds (SVOCs)		
Benzo(a)pyrene Dibenz(a,h)anthracene	Benzo(a)pyrene	Benzo(a)pyrene
Polychlorinated Biphenyls (PCBs)		
Aroclor-1254 Aroclor-1260 2,3,7,8-TCDD TEQ		Aroclor-1260

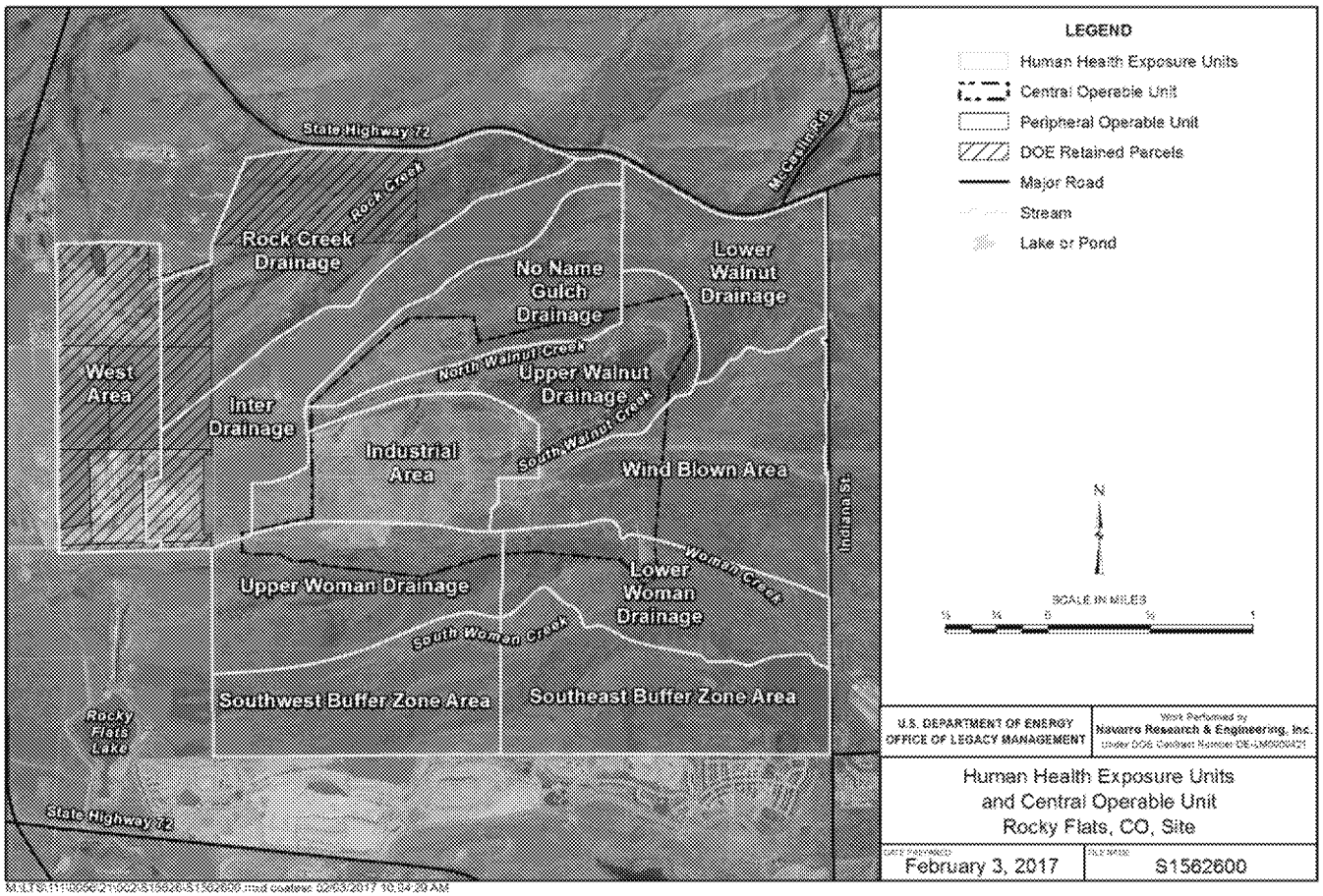

Figure C-1. Human Health Exposure Units and Central OU Boundary

C2.2 CRA Review Methodology

As an initial step in the CRA process, residual concentrations of constituents in soil for each EU were compared to preliminary remediation goals (PRGs) developed for a wildlife refuge worker (WRW). The PRGs represent concentrations for individual chemicals that would equate to a carcinogenic risk of 1×10^{-6} or a noncarcinogenic hazard quotient of 0.1 based on the exposure assumptions for the WRW. The 2006 CRA used a hazard quotient of 0.1 as an initial, conservative screening level; a hazard quotient of 1.0 is the maximum permissible limit. The PRGs were developed using toxicity data that were current at the time of the CRA and were developed for exposures to both surface and subsurface soils. PRGs for subsurface soils are higher than those for surface soils as it was assumed that the exposure frequency would be much lower (20 days per year compared to 230 days per year). The MDC for each detected constituent at each EU was compared to its respective PRG. If the MDC was less than the PRG, the constituent was eliminated from further consideration. If the MDC exceeded the PRG, the 95UCL of the mean for that constituent was compared to the PRG. If the 95UCL was less than the PRG, the constituent was eliminated from further consideration. If the 95UCL exceeded the PRG, the constituent was further evaluated based on frequency of detection, comparison to background concentrations, and professional judgement. Constituents passing through these remaining screening criteria were identified as COCs for each EU (Table C-2) and were further evaluated in the CRA. (Note that the sitewide AOI screening process and CRA EU-specific COC screening process were somewhat different and produced different results.) In the 2006 CRA, COCs were only identified for surface soils. All constituents in subsurface soils were eliminated by the 95UCL screen and no quantitative risks were calculated.

Table C-2. Surface Soil COCs Identified for Each EU in the CRA

Constituent	Exposure Unit											
	Industrial Area EU	Upper Woman Drainage EU	Wind Blown EU	No Name Gulch EU	Upper Walnut Drainage EU	Lower Woman Drainage EU	Rock Creek EU	Lower Walnut Drainage EU	Inter Drainage EU	West Area EU	Southwest Buffer Zone Area EU	Southeast Buffer Zone Area EU
Arsenic	X	-	X	-	-	-	-	-	-	-	-	-
Vanadium	-	-	-	X	-	-	-	-	-	-	-	-
2,3,7,8-TCDD	-	X	-	-	-	-	-	-	-	-	-	-
Benzo[a]pyrene	X	X	-	-	X	-	-	-	-	-	-	-
Plutonium 239/240	-	-	X	-	-	-	-	-	-	-	-	-

"X" = constituent was designated a COC in the 2006 CRA.
"- " = constituent was not designated a COC in the 2006 CRA.

C2.3 FYR Risk Evaluation

The following sections discuss the review methodology and results from this FYR risk evaluation for the COU. The sections have been separated into chemical and radionuclide constituents because the methodology for these evaluations were slightly different.

C2.3.1 Chemical Constituent Review Methodology

Because the first two steps of the COC screening process in the CRA relied on a comparison of residual soil concentrations with the WRW PRGs, any subsequent changes to exposure assumptions or toxicity values used to calculate the PRGs could change the outcome of the screening process. For this FYR risk evaluation, a methodology similar to that described above for the CRA was applied to determine the impact of changes to risk assessment parameters for surface soils. Figure C-2 presents the screening methodology. In lieu of recalculating site-specific PRGs for a WRW, this FYR risk evaluation utilized the EPA regional screening levels (RSLs) for industrial soil as a proxy for revised WRW PRGs. The RSLs incorporate current toxicity data and methodologies for the same exposure pathways of concern for the WRW. The default exposure assumptions for the industrial soil scenario are very similar to those used for the WRW for surface soils. Table C-3 compares the key assumptions used in RSL and site-specific PRG calculations. Where exposure factors are not the same, those used by EPA tend to be more conservative (i.e., assume a greater degree of exposure). Therefore, it was determined that the EPA industrial soil RSLs were an acceptable screening tool to represent updated surface soil WRW PRGs (referred to as "updated WRW RSLs" for the remainder of this appendix).

Commented [S1]: Do we need this new term? After explaining that the industrial soil RSL is considered an equivalent to the WRW PRGs, the term industrial soil RSL is the accurate and less confusing term.

The complete list of surface soil PRGs developed for the CRA were compared to the updated WRW RSLs (EPA 2016). Of the more than 200 original PRGs that were evaluated, slightly more than half were higher than the updated values. The vast majority of the lower RSL values were organic chemicals and many are considered to be volatile organic compounds (VOCs). EPA has recently finalized guidance on vapor intrusion (EPA 2015) and as a result has updated information on many VOCs included in their RSL tables. Additionally, the EPA approach to evaluating risks for the inhalation pathway was finalized in 2009. The methodology used in the CRA reflects older guidance for estimating exposures for this pathway. It is likely that a combination of these factors explain why such a large number of the PRGs are higher than current RSLs. Decreases for most constituents were within an order of magnitude, but RSLs for a few constituents are several orders of magnitude lower than PRGs (e.g., cyclohexane).

Where PRGs were lower than current RSLs, it was assumed that results of the original screening process are still valid. Where RSLs were lower than PRGs, a rescreening of the EU statistical data was performed. EPA RSLs that were lower than PRGs were compared to data presented in the CRA for each EU. The analytical data (MDCs and 95UCL values) used in this FYR review are the same data used in the 2006 CRA; no new data was collected to support this FYR review. The MDCs and 95UCLs used in the surface soil screening were compared to the RSLs. If 95UCL data were not already tabulated, a 95UCL was calculated from statistical data provided in the CRA. If MDCs or 95UCLs were lower than the current RSLs, constituents were eliminated from further consideration. All other constituents were retained for further evaluation. Table C-4 presents the results of the chemical screening process by EU; Table C-5 summarizes the screening process by constituent name.

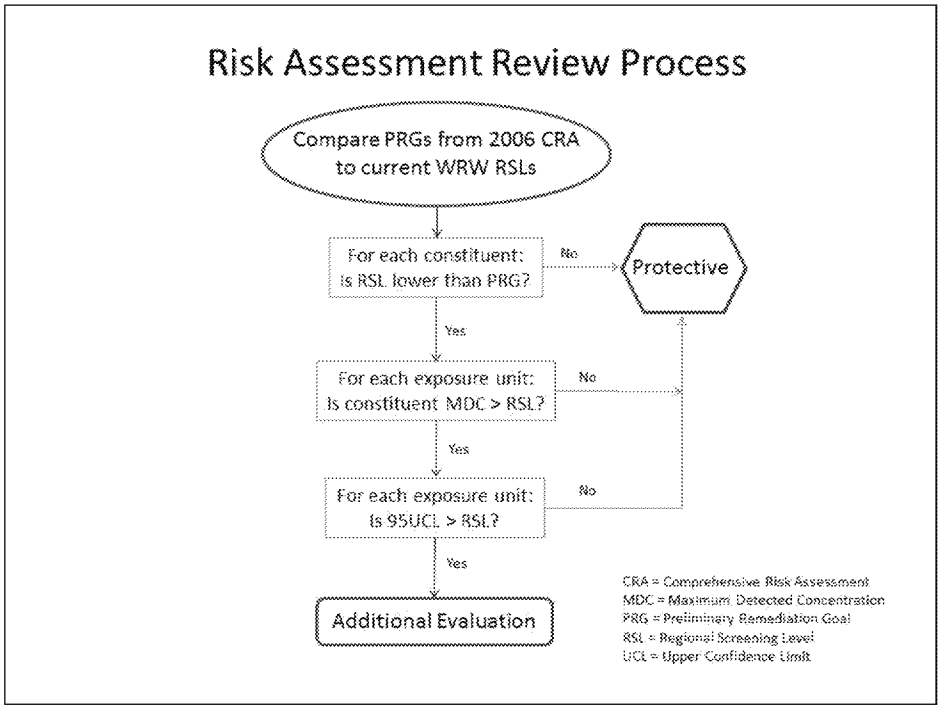

Figure C-2. Risk Assessment Review Process

Table C-3. Comparison of key exposure assumptions for RSLs and PRGs

Exposure Factor (units)	EPA RSL default value	WRW PRG assumption
Frequency of exposure (days/yr)	250	Surface soils—230 Subsurface soils--20
Exposure duration (years)	25	18.7
Exposure time (hr/day)	8	8
Soil ingestion rate (mg/day)	100	100
Adult body weight (kg)	80	70
Skin surface area (cm^2)	3527	3300

Table C-4. Surface Soil Chemical Constituent Screening Results by EU

Constituent	Industrial Area EU	Upper Woman Drainage EU	Wind Blown EU	No Name Gulch EU	Upper Walnut Drainage EU	Lower Woman Drainage EU	Rock Creek EU	Lower Walnut Drainage EU	Inter Drainage EU	West Area EU	Southwest Buffer Zone Area EU	Southeast Buffer Zone Area EU
Arsenic	X	-	X	-	-	-	-	-	-	-	-	-
Vanadium	-	-	-	X	-	-	-	-	-	-	-	-
2,3,7,8-TCDD	-	X	-	-	-	-	-	-	-	-	-	-
Aroclor 1254	X	-	X	X	-	-	-	-	-	-	-	-
Aroclor 1260	X	-	-	-	-	-	-	-	-	-	-	-
Benz[a]anthracene	X	X	-	-	-	-	-	-	-	-	-	-
Benzo[a]pyrene	X	X	X	X	X	-	-	-	-	-	-	-
Benzo[b]fluoranthene	X	X	-	-	-	-	-	-	-	-	-	-
Cobalt	X	-	-	-	-	-	-	-	-	-	-	-
Diben[a,h]anthracene	X	X	-	-	-	-	-	-	-	-	-	-
Indeno[1,2,3-cd]pyrene	-	X	-	-	-	-	-	-	-	-	-	-
Lead and Compounds	-	-	-	X	-	-	-	-	-	-	-	-
Mercury (elemental)	X	-	-	-	-	-	-	-	-	-	-	-
Naphthalene	-	X		-	-	-	-	-	-	-	-	-
Nitroso-di-N-propylamine, N-	-	-	X	-	-	-	-	-	-	-	-	-
Uranium (Soluble Salts)	X	X	-	-		-	-	-	-	-	-	-

"X" = constituent maximum detected concentration (MDC) > WRW RSL
Shaded boxes indicate 95UCL > WRW RSL
"-" = constituent MDC or 95UCL < WRW RSL
Arsenic and vanadium were included in this table because they were identified as COCs in the CRA and 95UCL exceeds PRG.

Table C-5. Surface Soil Chemical Constituent Screening Results by Constituent

All Constituents with PRGs	Constituents where EPA RSL < PRG	Constituents where EPA RSL < PRG (any EU)	Constituents where MDC > EPA RSL (any EU)
Acenaphthene	1,1,1-Trichloroethane,	1,1,1-Trichloroethane,	2,3,7,8-TCDD,
Acenapthylene	1,1,2,2-Tetrachloroethane,	1,1,2,2-Tetrachloroethane,	~Aroclor 1254
Acetone	1,1,2-Trichloro-1,2,2-trifluoroethane,	1,1,2-Trichloro-1,2,2-trifluoroethane,	~Aroclor 1260
Acrolein	1,1,2-Trichloroethane,	1,2,3-Trichloropropane,	Benz[a]anthracene
Acrylonitrile	1,1-Dichloroethane,	1,2,4-Trichlorobenzene,	Benzo[a]pyrene
Alachlor	1,2,3-Trichloropropane,	1,2-Dichloropropane,	Benzo[b]fluoranthene
Aldicarb	1,2,4-Trichlorobenzene,	2,4,6-Trichlorophenol,	Cobalt
Aldicarb Sulfone	1,2-Dibromo-3-chloropropane	2,4-Dimethylphenol,	~Dibenz[a,h]anthracene
Aldicarb sulfoxide	1,2-Dichlorobenzene,	2,4-Dinitrophenol,	~Indeno[1,2,3-cd]pyrene
Aldrin	1,2-Dichloroethane,	2,3,7,8-TCDD,	~Lead and Compounds
Aluminum	1,2-Dichloropropane,	2-Butanone (Methyl Ethyl Ketone)	~Mercury (elemental)
Ammonia	1,2-Diphenylhydrazine,	2-Methylnaphthalene,	~Naphthalene
~Anthracene	1,4-Dioxane,	4-methyl-2-pentanone (Methyl Isobutyl Ketone)	Nitroso-di-N-propylamine, N-
Antimony (metallic)	2,4,6-Trichlorophenol,	Acetone	Uranium (Soluble Salts)
~Aroclor 1016	2,4-Dimethylphenol,	~Aroclor 1242	
~Aroclor 1221	2,4-Dinitrophenol,	~Aroclor 1248	
~Aroclor 1232	2,4-Dinitrotoluene,	~Aroclor 1254	
~Aroclor 1242	2,6-Dinitrotoluene,	~Aroclor 1260	
~Aroclor 1248	2,3,7,8-TCDD,	Benzene	
~Aroclor 1254	2-Butanone (Methyl Ethyl Ketone)	Benzo[a]anthracene	
~Aroclor 1260	2-Chloronaphthalene (Beta-)	Benzo[a]pyrene	
Arsenic, Inorganic	2-Methylnaphthalene,	Benzo[b]fluoranthene	
Atrazine	3,3'-Dichlorobenzidine,	Benzo[k]fluoranthene	
Barium	4,6-Dinitro-o-cresol,	Benzyl Alcohol	
Benzene	4-Chloroaniline	Bis(2-ethylhexyl)phthalate	
Benzidine	4-methyl-2-pentanone (Methyl Isobutyl Ketone)	Bromodichloromethane	
~Benz[a]anthracene	4-Nitroaniline,	Bromomethane	
~Benzo[a]pyrene	Acetone	Butyl Benzyl Phthalate	
~Benzo[b]fluoranthene	Acrolein	Carbon Disulfide	
~Benzo[g,h,i]perylene	Acrylonitrile	Carbon Tetrachloride	
~Benzo[k]fluoranthene	~Aroclor 1221	Chlorobenzene	
Benzoic Acid	~Aroclor 1232	Chloroform	
Benzyl Alcohol	~Aroclor 1242	Chloromethane (methyl chloride)	
Beryllium and compounds	~Aroclor 1248	Chrysene	
Bis(2-chloroethyl)ether	~Aroclor 1254	Cobalt	
Bis(2-chloro-1-methylethyl) ether	~Aroclor 1260	DDD	
Bis(2-ethylhexyl)phthalate	Atrazine	DDE, p,p'-	
Boron And Borates Only	Benzene	DDT	
Bromodichloromethane	Benzidine	~Dibenz[a,h]anthracene	
Bromoform	Benz[a]anthracene	Dibenzofuran	
Bromomethane	Benzo[a]pyrene	Dieldrin	
2-Butanone (Methyl Ethyl Ketone)	Benzo[b]fluoranthene	Dimethylphthalate	
Butyl Benzyl Phthalate	Benzo[k]fluoranthene	di-N-Octyl Phthalate	
Cadmium (Diet)	Benzyl Alcohol	Ethylbenzene	
Carbazole	Bis(2-chloroethyl)ether	~Fluorene	
Carbofuran	Bis(2-ethylhexyl)phthalate	Hexachlorobenzene	
Carbon Disulfide	Bromodichloromethane	Hexachlorobutadiene	
Carbon Tetrachloride	Bromoform	~Indeno[1,2,3-cd]pyrene	
Chlordane-alpha	Bromomethane	Isophorone	
Chlordane-beta	Butyl Benzyl Phthalate	~Lead and Compounds	
Chlordane-gamma	Carbon Disulfide	Lithium	
4-Chloroaniline	Carbon Tetrachloride	~Mercury (elemental)	
Chlorobenzene	Chlordane-gamma	~Naphthalene	
Ethyl Chloride (Chloroethane)	Chlorobenzene		
Chloroform			

Table C-5. Surface Soil Chemical Constituent Screening Results by Constituent (continued)

All Constituents with PRGs	Constituents where EPA RSL < PRG	Constituents where EPA RSL < PRG (any EU)	Constituents where MDC > EPA RSL (any EU)
Chloromethane (methyl chloride)	Chloroform	Nitroso-di-N-propylamine, N-	
4-Chloro-3-methylphenol (Cresol, p-chloro-m-)	Chloromethane (methyl chloride)	Pentachlorophenol	
~2-Chloronaphthalene (Beta-)	Chlorpyrifos	Styrene	
Chlorophenol, 2-	Chrysene	Thallium (Soluble Salts)	
Chlorpyrifos	Cobalt	Uranium (Soluble Salts)	
Chromium(III), Insoluble Salts	~Cyanide (CN-)	Xylenes	
Chromium(VI)	Cyclohexane		
~Chrysene	DDD		
Cobalt	DDE, p,p'-		
Copper	DDT		
~Cyanide (CN-)	Di(2-ethylhexyl)adipate		
Cyclohexane	~Dibenz[a,h]anthracene		
DDD	Dibenzofuran		
DDE, p,p'-	Dibromochloromethane		
DDT	Dichlorodifluoromethane		
Dalapon	Dieldrin		
Demeton	Dimethoate		
~Dibenz[a,h]anthracene	Dimethylphthalate		
Dibenzofuran	di-N-Octyl Phthalate		
Dibromochloromethane	Ethyl Acetate		
1,2-Dibromo-3-chloropropane	Ethylbenzene		
Dibutyl Phthalate	~Fluorene		
Dicamba	Heptachlor		
Dichlorobenzene, 1,2-	Hexachlorobenzene		
Dichlorobenzene, 1,3-	Hexachlorobutadiene		
Dichlorobenzene, 1,4-	Hexachlorocyclohexane, Alpha-		
Dichlorobenzidine, 3,3'-	Hexachlorocyclohexane, Beta-		
Dichlorodifluoromethane	Hexachlorocyclohexane, Gamma- (Lindane)		
Dichloroethane, 1,1-	Hexachlorocyclohexane, Technical		
Dichloroethane, 1,2-	Hexachlorocyclopentadiene		
Dichloroethylene, 1,1-	Hexachlorodibenzo-p-dioxin		
Dichloroethene, 1,2- (total)	Hexachloroethane		
Dichlorophenol, 2,4-	HxCDD, 1,2,3,6,7,8-		
Dichlorophenoxy Acetic Acid, 2,4-	HxCDD, 1,2,3,7,8,9-		
Dichlorophenoxy)butyric Acid, 4-(2,4-	~Indeno[1,2,3-cd]pyrene		
Dichloropropane, 1,2-	Isophorone		
Dichloropropane, 1,3-	~Lead and Compounds		
Dichloropropene, cis-1,3-	Lithium		
Dichloropropene, trans-1,3-	~Mercury (elemental)		
Dieldrin	Methyl Methacrylate		
Diethyl Ether (Ethyl Ether)	Methyl tert-Butyl Ether (MTBE)		
Di(2-ethylhexyl)adipate	Mirex		
Diethyl Phthalate	~Naphthalene		
Dimethoate	Nitrobenzene		
Dimethylphenol, 2,4-	Nitrosodiethylamine, N-		
Dimethylphthalate	Nitrosodimethylamine, N-		
Dinitro-o-cresol, 4,6-	Nitroso-di-N-butylamine, N-		
Dinitrophenol, 2,4-	Nitroso-di-N-propylamine, N-		
Dinitrotoluene, 2,4-	Nitrosodiphenylamine, N-		
Dinitrotoluene, 2,6-	Nitrosopyrrolidine, N-		
di-N-Octyl Phthalate	Pentachlorophenol		
Dinoseb	p-Nitrotoluene,		
Dioxane, 1,4-			
~TCDD, 2,3,7,8-			

Table C-5. Surface Soil Chemical Constituent Screening Results by Constituent (continued)

All Constituents with PRGs	Constituents where EPA RSL < PRG	Constituents where EPA RSL < PRG (any EU)	Constituents where MDC > EPA RSL (any EU)
Diphenylhydrazine, 1,2-	Simazine		
Diquat	Styrene		
Endosulfan I	Thallium (Soluble Salts)		
Endosulfan II	Toxaphene		
Endosulfan Sulfate	Uranium (Soluble Salts)		
Endosulfan (technical)	Vinyl Acetate		
Endrin	Vinyl Chloride		
Endrin aldehyde	Xylene, m-		
Endrin ketone	Xylene, o-		
Ethyl Acetate	Xylene, P-		
Ethylbenzene	Xylenes		
Ethylene dibromide (Dibromoethane, 1,2-)			
~Fluoranthene			
~Fluorene			
Fluorine (Soluble Fluoride)			
Glyphosate			
Guthion (Azinphos-methyl)			
Heptachlor			
Heptachlor Epoxide			
Hexachlorobenzene			
Hexachlorobutadiene			
Hexachlorocyclohexane, Alpha-			
Hexachlorocyclohexane, Beta-			
Hexachlorocyclohexane, Gamma- (Lindane)			
Hexachlorocyclohexane, Delta-			
Hexachlorocyclohexane, Technical			
Hexachlorocyclopentadiene			
Hexachlorodibenzo-p-dioxin			
HxCDD, 1,2,3,6,7,8-			
HxCDD, 1,2,3,7,8,9-			
Hexachloroethane			
~Indeno[1,2,3-cd]pyrene			
Iron			
Isobutyl Alcohol			
Isophorone			
Isopropylbenzene (Cumene)			
~Lead and Compounds			
Lithium			
Manganese (Diet)			
~Mercury (elemental)			
Methoxychlor			
MCPA			
MCPP			
Methylene Chloride			
Methyl Methacrylate			
~Methylnaphthalene, 2-			
Methyl Isobutyl Ketone (4-methyl-2-pentanone)			
2-Methylphenol (Cresol, o-)			
4-Methylphenol (Cresol, p-)			
Methyl tert-Butyl Ether (MTBE)			

Table C-5. Surface Soil Chemical Constituent Screening Results by Constituent (continued)

All Constituents with PRGs	Constituents where EPA RSL < PRG	Constituents where EPA RSL < PRG (any EU)	Constituents where MDC > EPA RSL (any EU)
Mirex			
Molybdenum			
~Naphthalene			
Nickel Soluble Salts			
Nitrate			
Nitrite			
Nitroaniline, 2-			
Nitroaniline, 4-			
Nitrobenzene			
Nitrophenol, 4-			
Nitroso-di-N-butylamine, N-			
Nitrosodiethylamine, N-			
Nitrosodimethylamine, N-			
Nitrosodiphenylamine, N-			
Nitroso-di-N-propylamine, N-			
Nitrosopyrrolidine, N-			
Nitrotoluene, p-			
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)			
Oxamyl			
Parathion			
Pentachlorobenzene			
Pentachlorophenol			
Phenanthrene			
Phenol			
Picloram			
~Pyrene			
Selenium			
Silver			
Simazine			
Strontium, Stable			
Styrene			
Sulfide			
Tetrachlorobenzene, 1,2,4,5-			
Tetrachloroethane, 1,1,1,2-			
Tetrachloroethane, 1,1,2,2-			
Tetrachloroethylene			
Tetrachlorophenol, 2,3,4,6-			
Thallium (Soluble Salts)			
Tin			
Titanium			
Toluene			
Toxaphene			
Trichlorobenzene, 1,2,4-			
Trichloroethane, 1,1,1-			
Trichloroethane, 1,1,2-			
Trichloroethylene			
Trichlorofluoromethane			
Trichlorophenol, 2,4,5-			
Trichlorophenol, 2,4,6-			
Trichlorophenoxypropionic acid, -2,4,5			
Trichloropropane, 1,2,3-			
Trichloro-1,2,2-trifluoroethane, 1,1,2-			
Trinitrotoluene, 2,4,6-			
Uranium (Soluble Salts)			
Vanadium and Compounds			

Table C-5. Surface Soil Chemical Constituent Screening Results by Constituent (continued)

All Constituents with PRGs	Constituents where EPA RSL < PRG	Constituents where EPA RSL < PRG (any EU)	Constituents where MDC > EPA RSL (any EU)
Vinyl Acetate Vinyl Chloride Xylene, P- Xylene, m- Xylene, o- Xylenes Zinc and Compounds			
Notes: First column lists all constituents for which WRW PRGs were developed. The constituents are arranged in the same order as they were in the CRA methodology document where the PRGs were developed (DOE 2004). The second column lists all constituents where the May 2016 EPA RSLs were lower than the WRW PRGs. The constituents are arranged in the order used in the PRG screening tables that were included in the CRA for each EU. That same order is used for subsequent columns. The third column includes all constituents that were carried through the screening process for any EU. The last column contains all constituents with a MDC that exceeded an EPA RSL. Note that arsenic and vanadium are not carried past the first column in this table because the EPA RSLs are greater than the WRW PRGs and rescreening isn't required.			

Because no COCs were identified in the CRA for subsurface soils and because the reevaluation of surface soil data discussed above indicated that the CRA process was sound in identifying COCs, a more targeted approach was taken in this FYR to answer Question B with regard to subsurface soils. An abbreviated PRG list was used for subsurface soil screening based on the results of the surface soil screening process. This included all constituents for which any surface soil MDC exceeded the surface soil PRG (constituents listed in Table C-4 and last column in Table C-5); tetrachloroethene was also added to this list as it was identified as a subsurface AOI in the RI/FS (Table C-1). The constituents evaluated along with screening results are listed in Table C-6. The current WRW RSLs were multiplied by 11.5 to obtain current estimates of subsurface WRW PRGs. The screening with this smaller set of PRGs proceeded in the same manner as the surface soil FYR evaluation described above.

Table C-6. Subsurface Soil Chemical Constituent Screening Results by EU

Constituent	Industrial Area EU	Upper Woman Drainage EU	Wind Blown EU	No Name Gulch EU	Upper Walnut Drainage EU	Lower Woman Drainage EU	Rock Creek EU	Lower Walnut Drainage EU	Inter Drainage EU	West Area EU	Southwest Buffer Zone Area EU	Southeast Buffer Zone Area EU
2,3,7,8-TCDD	-	-	-	-	-	-	-	-	-	-	-	-
Aroclor 1254	X	-	-	-	-	-	-	-	-	-	-	-
Aroclor 1260	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic	X	-	-	-	-	-	-	-	-	-	-	-
Benz[a]anthracene	-	X	-	-	-	-	-	-	-	-	-	-
Benzo[a]pyrene	X	X	X	-	-	-	-	-	-	-	-	-
Benzo[b]fluoranthene	-	X	-	-	-	-	-	-	-	-	-	-
Cobalt	-	X	-	-	-	-	-	-	-	-	-	-
Diben[a,h]anthracene	X	-	-	-	-	-	-	-	-	-	-	-
Indeno[1,2,3-cd]pyrene	-	-	-	-	-	-	-	-	-	-	-	-
Lead and Compounds	-	-	-	-	-	-	-	-	-	-	-	-

Constituent	Industrial Area EU	Upper Woman Drainage EU	Wind Blown EU	No Name Gulch EU	Upper Walnut Drainage EU	Lower Woman Drainage EU	Rock Creek EU	Lower Walnut Drainage EU	Inter Drainage EU	West Area EU	Southwest Buffer Zone Area EU	Southeast Buffer Zone Area EU
Mercury (elemental)	-	-	-	-	-	-	-	-	-	-	-	-
Naphthalene	X	-	-	-	-	-	-	-	-	-	-	-
Nitroso-di-N-propylamine, N-	-	-	-	-	-	-	-	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-	-	-	-	-	-	-	-
Vanadium	-	-	-	-	-	-	-	-	-	-	-	-
Uranium (Soluble Salts)	X	-	-	-	-	-	-	-	-	-	-	-

"X" indicates MDC > EPA RSL
"-" indicates MDC< EPA RSL
Arsenic and vanadium were included in this table because they were identified as COCs in the CRA and 95UCL exceeds WRW PRG.

C2.3.2 Chemical Constituent Evaluation Results

Surface Soils. As was the case in the original CRA screening process, nearly all constituents were eliminated in this FYR risk evaluation based on the MDC comparison screen. Despite the lower EPA RSLs, the MDCs were typically much lower than the screening values. Very few constituents were retained by the RSL screen that were not also retained by the PRG screen. Among these is uranium, for which EPA has recently recommended a much lower toxicity value (EPA 2016). Most constituents passing the RSL screen were subsequently eliminated based on the 95UCL comparison or following additional evaluation (e.g., frequency of detection [<5 percent]). Of the constituents evaluated in this FYR evaluation screening process, only four constituents passed through the 95UCL screen. These are summarized in Table C-7.

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Table C-7. Chemical Constituents and EUs where 95UCL Exceeds Current Screening Level

	Exposure Unit											
Constituent	Industrial Area EU	Upper Woman Drainage EU	Wind Blown EU	No Name Gulch EU	Upper Walnut Drainage EU	Lower Woman Drainage EU	Rock Creek EU	Lower Walnut Drainage EU	Inter Drainage EU	West Area EU	Southwest Buffer Zone Area EU	Southeast Buffer Zone Area EU
Arsenic	X	-	X	-	-	-	-	-	-	-	-	-
Vanadium	-	-	-		-	-	-	-	-	-	-	-
2,3,7,8-TCDD		X	-	-	-	-	-	-	-	-	-	-
Benzo[a]pyrene	X	X	-	X	X	-	-	-	-	-	-	-
Diben[a,h]anthracene	-	X	-	-	-	-	-	-	-	-	-	-

"X" indicates constituent would be considered a COC based on CRA screening methodology.
"-" indicates constituent not considered a COC in CRA.
Shaded boxes differ with the CRA results.

As in the original CRA, dioxin was identified as a COC for the Upper Woman Drainage EU (UWOEU) and benzo(a)pyrene as a COC for the Industrial Area EU (IAEU), UWOEU, and the Upper Walnut Drainage EU. Based on the rescreening process, benzo(a)pyrene would also be considered as a COC for the No Name Gulch EU, with concentrations slightly above the current RSL. The rescreening process also confirmed that arsenic is still considered a COC for the IAEU and Wind Blown EU based on current RSL concentrations; estimated risk levels associated with residual arsenic would be similar to that in the CRA. The arsenic 95UCL for all the other EUs also exceeded the PRG (and the current RSL) but arsenic was eliminated as a COC for those EUs in the CRA based on subsequent screens; it is assumed that the arsenic screening process is still valid for those EUs. Based on the current vanadium RSL, vanadium would not be a COC. The vanadium PRG is based on a lower toxicity value than is being used by EPA; however, vanadium is still undergoing study and this value could change in the future. As in the CRA, dibenz[a,h]anthracene did pass through the 95UCL screen for the UWOEU; however, the frequency of detection was less than 5% for this constituent and it was eliminated on that basis. For the most part, the rescreening process confirmed the results of the CRA.

Subsurface Soils. The MDCs for a number of constituents exceeded the revised PRG screening values. However, all constituents dropped out based on the 95UCL screen and the reevaluation confirmed that there are no subsurface COCs.

The vapor intrusion pathway was identified in the CRA as a potentially complete pathway for VOCs in subsurface soils, including those at depths greater than 8 feet. Most of the AOIs identified for subsurface soils in the RI/FS are VOCs (Table C-1). EPA has finalized guidance for evaluating the vapor intrusion pathway (EPA 2015) and has provided guidance for evaluating this pathway in during five-year reviews (EPA 2012c). Updated toxicity data are also available for some VOCs that are identified as AOIs at subsurface depths > 8 ft (e.g., tetrachloroethene, trichloroethene). However, institutional controls are in place at the COU that eliminate the vapor intrusion pathway by prohibiting the construction of habitable structures. RAOs and cleanup goals remain valid and are not affected by updated guidance and toxicity data as long as institutional controls remain in place.

In addition to the toxicity values discussed above, EPA is reviewing the toxicity of two COCs for the COU—arsenic and benzo(a)pyrene. The arsenic study suggests that current methods of estimating risks from arsenic due to soil ingestion likely overestimate actual risks. The EPA study of benzo(a)pyrene (EPA 2014) is not yet completed and results cannot be cited at this time. Changes in slope factors may be forthcoming, but are not yet available. None of these additional studies affect the protectiveness of the remedy.

C2.3.3 Radiological Constituent Review Methodology

As various scientific radiological organizations and communities (e.g., Center for Radiation Protection Knowledge, International Commission on Radiological Protection [ICRP], EPA Federal Guidance Reports (FGRs), etc.) gain greater knowledge of the effects of ionizing radiation on humans, changes are made to their supporting and guidance documents, that are then used in radiological risk and dose calculation tools, such as the online EPA PRG calculator and the RESRAD dose model.

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Information from the current EPA PRG calculator was used in this FYR risk evaluation to determine if the risks from radionuclides to the WRW in the COU remain within the acceptable CERCLA risk range (i.e., 1 x 10^{-4} to 1 x 10^{-6}). Information in the online PRG calculator incorporates the numerous changes to toxicity factors that have occurred since 2006, including revisions specific to plutonium and uranium. In fact, eighteen revisions have been made to the PRG calculator since 2001. In September 2014, a significant revision was adopted that follows EPA recommendations concerning use of exposure parameters from the EPA Exposure Factors Handbook (EPA 2011). New slope factors for radionuclides have been programmed into the calculator that were derived following FGRs 12 and 13 using the updated isotope list from ICRP107. The cancer slope factors used by the PRG calculator are provided by the Center for Radiation Protection Knowledge. Examples of some of the slope factors used in the CRA (2006) compared to those found in the current EPA PRG calculator (2017) are shown in Table C-8.

Table C-8.Comparison of Slope Factors for Various Pathways

Isotope	2006	2017
Adult Ingestion		
Am-241	9.1E-11	9.1E-11
Pu-239	1.21E-10	1.21E-10
U-234	5.11E-11	5.11E-11
U-235	4.92E-11	4.92E-11
U-238	4.66E-11	4.66E-11
Adult Inhalation		
Am-241	2.81E-08	3.77E-08
Pu-239	3.33E-08	5.55E-08
U-234	1.14E-08	2.78E-08
U-235	1.01E-08	2.50E-08
U-238	9.32E-09	2.36E-08
Adult External Exposure		
Am-241	2.76E-08	2.77E-08
Pu-239	2.00E-10	2.09E-10
U-234	2.52E-10	2.53E-10
U-235	5.18E-07	5.51E-07
U-238	4.99E-11	1.24E-10

Information from the current EPA PRG calculator was used in this FYR evaluation to determine if the risk from radionuclides to the WRW in the COU remains within the acceptable CERCLA risk range. To perform the FYR radiological risk evaluation, the input parameters used in the 2006 CRA for the WRW used with information from the current EPA PRG calculator to obtain updated PRG values that represent a 1 x 10^{-6} level of risk. These updated PRG values were then compared to the WRW PRG values from the 2006 CRA. For completeness, this FYR review considered Pu-239/240 (the only radionuclide COC identified in the 2006 CRA), Am-241, U-234, U-235, and U-238. The americium and uranium isotopes represent the other primary radionuclides associated with Rocky Flats historical operations. This review methodology does not require input of site-specific analytical data. As such, no new soil analytical data were

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collected for this FYR risk evaluation. Changes in PRG values (from 2006 to 2017) are likely the result of changes made to either the calculators and how they function (e.g., formulas used in the calculations process have been modified/updated) or the scientific data that the calculators use to compute risk (e.g., isotopic cancer slope factors or dose conversion factors), or a combination of both.

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Limitations on Use of the EPA PRG Calculator. During the review/recalculation process, it was noted that the current online PRG calculator requires additional information that was not used in the 2006 PRG calculations, and thus, not available for input. While the EPA PRG calculator contains default values for all of these additional inputs, it was determined that the use of default values would create an entirely new scenario, distinct from that evaluated in 2006. The resulting comparison of these updated PRGs calculated by the PRG calculator to the 2006 PRGs would not be appropriate or meaningful. In order to address this issue, updated PRG values were calculated using a Microsoft Excel spreadsheet (or Excel calculator) created to run the various applicable formulas found in the current EPA PRG calculator. Significant effort was taken to accurately recalculate PRG values using the 2006 and earlier data sets, by checking the results of the Excel spreadsheet against known values. Risk slope factors from the online 2017 EPA PRG calculator, as well as decay constants of the isotopes being used in the calculation, are used by the Excel calculator to calculate current (2017) PRG values. Calculations performed in the Excel spreadsheet did not take into account progeny from the parent isotopes, similar to what occurs in the EPA PRG calculator. Verification of the Excel spreadsheet calculator was performed using available data inputs from the 2006 CRA (taken from the 2004 CRA methodology document (DOE, 2004), the 2002 radiological screening levels used as cleanup levels during accelerated remedial actions at the Site (add reference), and the programmatic PRGs (PPRGs) calculated in 1994 for the OU3 baseline risk assessment (DOE, 1994). Section C3.0 discusses the Excel spreadsheet results in relation to earlier datasets used in the verification.

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C2.3.4 Radionuclide Constituent Evaluation Results

Table C-9 contains the PRG comparison results for the WRW in the COU. As shown in the table, the COU remains within the EPA acceptable risk range of 1 x 10^{-6} for each radionuclide evaluated. Therefore, even though changes have occurred to various toxicity factors and other risk input since 2006, the remedy in the COU remains protective.

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Table C-9. PRG Comparison for WRW in the COU
(pCi/g at 10^{-6} risk level)

Isotope	2006 CRA PRG	2017 PRG
Am-241	7.69	8.81
Pu-239	9.78	11.85
U-234	25.31	29.96
U-235	1.05	1.06
U-238	29.33	34.38

C2.3.5 Radiological Dose Assessment Review

In addition to human health risk calculations performed in the CRA, a radiation dose assessment for exposure to residual radionuclide contamination in surface soil and subsurface soil was also completed. The purpose of the dose assessment was to demonstrate compliance with the annual dose limits in Colorado Radiation Control Regulations (Title 6 *Code of Colorado Regulations* 1007-1, Part 4 [6 CCR 1007-1, Part 4]), which were identified as ARARs in the CAD/ROD (DOE 2006). For radiological sites that do not allow for unrestricted use, as is the case for the COU, Colorado regulations require that institutional controls be in place that reasonably assure that the total effective dose equivalent from residual radioactivity at the site does not exceed 25 mrem/year (6 CCR 1007-4.61.2).

RESRAD-ONSITE is a pathway analysis computer code that calculates radiation doses and cancer risks to a critical population group and can be used to derive cleanup criteria for radioactively contaminated soils. Since 2002, eight revisions have been made to RESRAD-ONSITE (RESRAD). In 2014, RESRAD was revised to allow dose conversion factor database and software capability for ICRP107. In 2016, RESRAD was revised to provide options to choose between the ICRP38 radionuclide decay database and the ICRP107 radionuclide decay database; ICPR38 supports the use of either ICRP26/30 or ICRP60/72 based dose coefficients, and ICRP107 supports the use of ICRP60 based dose coefficients from DCFPAK 3.02.

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Changes to ICRP versions. Within the RESRAD-ONSITE Computer Code program (software or calculator), (Revision 7.2, July 20, 2017), both DCFs and slope factors are used. For the verification calculations performed in 2017, the program was first set to use ICRP 38 for radionuclide transformations. This configuration defaults to ICRP 72 (selectable from adult to infant) for the internal dose library, ICRP 60 for the external dose library, and FGR 13 morbidity risk factors (Figure C-3). The ICRP 38 configuration best approximates the older 2006 (Revision 6.3) version of the calculator that was used in 2006, as ICRP 38 was replaced by ICRP 107 in 2008 in the software program. Then the calculator was set to use ICRP 107 for radionuclide transformations. This configuration defaults to DOE STD-1196-2001 Reference Person (selectable from adult to infant) for the internal dose library, DCFPAK 3.02 for the external dose library, and DCFPAK 3.02 morbidity risk factors (Figure C-4). *Oak Ridge National Laboratory, Calculation of Slope Factors and Dose Coefficients, September 2014* (https://epa-prgs.ornl.gov/radionuclides/SlopesandDosesFinal.pdf) provides detailed information regarding the development of the risk factors and does coefficients used in the current RESRAD-

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ONSITE software program. Both the ICRP 38 and ICRP 107 versions of the RESRAD-ONSITE calculator were run (using the old data), to provide an understanding of the revisions to the RESRAD-ONSITE calculator, based on the results of the calculator runs.

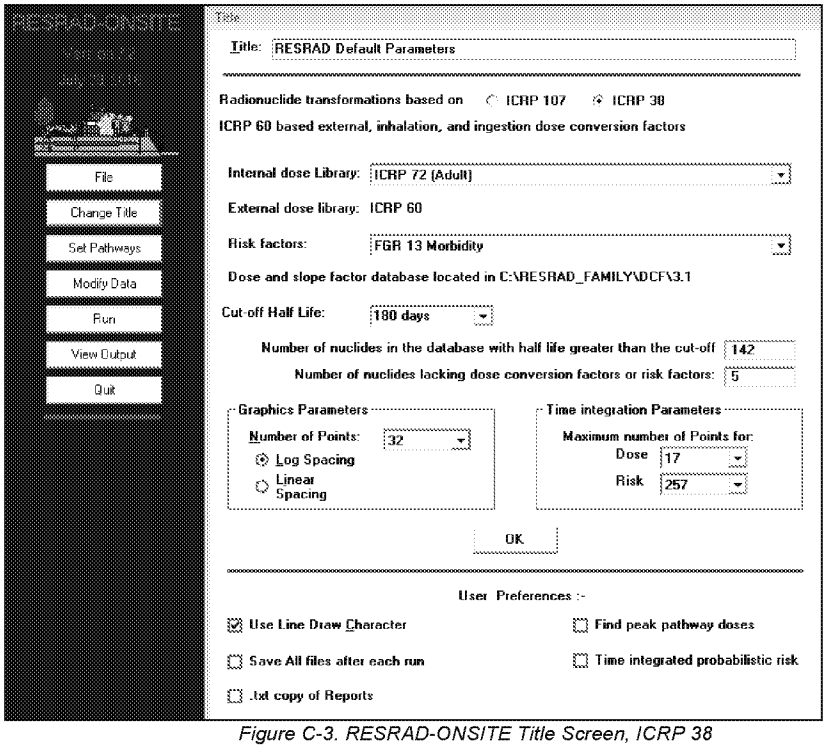

Figure C-3. RESRAD-ONSITE Title Screen, ICRP 38

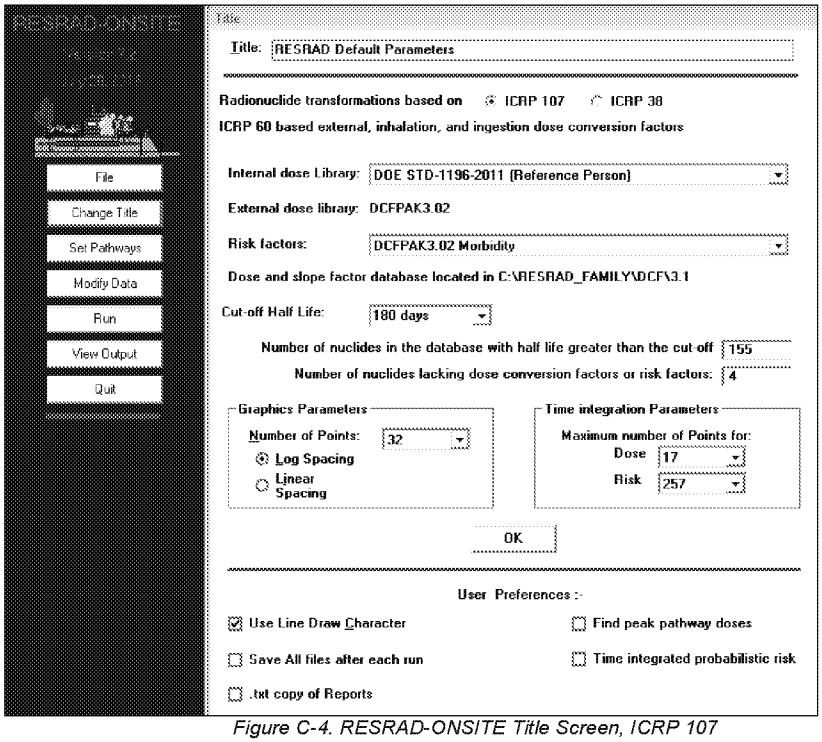

Figure C-4. RESRAD-ONSITE Title Screen, ICRP 107

Changes to Dose Conversion Factors. RESRAD-ONSITE dose conversion factors (DCF) were evaluated for changes between the 2006 and 2017 software program (versions 6.3 and 7.2 and ICRP 38 and ICRP 107, respectively). Only the key isotopes (those input in the calculator for the modeling runs performed in both 2006/2017; Am-241, Pu-239, U-234, U-235 and U-238) were evaluated, as progeny isotope DCF values would likely follow suit of the parent isotope. Below are the DCF values for the inhalation and ingestion pathway, as presented in the calculator.

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As shown in Figures C-10 and C-11, most DCF values changed between the 2006 and 2017 calculator versions for the parent and progeny isotopes. Shaded cells in the tables are the key isotopes that were input into the calculators. Non-shaded table cells are isotopes that are introduced by the RESRAD-ONSITE calculator as a result of progeny ingrowth during the 1,000 year evaluation time period. While those added isotopes add little value to the comparison aspect of the review, they represent the various DCFs for the radionuclides that in-grow over the 1,000 year evaluation time period.

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Table C-10. RESRAD Dose Conversion Factors (2006 and 2017, Am & Pu, Adult)

Dose conversion factors for inhalation, mrem/pCi:					
Menu Code	Parameter	2006 ICRP 72 Value	2017 ICRP 38 Value	2017 ICRP 107 Value	Parameter Name
B-1	Ac-227+D	6.724E+00	2.104E+00	6.714E-01	DCF2(1)
B-1	Am-241	1.600E-01	3.552E-01	3.630E-01	DCF2(2)
B-1	Np-237+D	5.400E-01	1.850E-01	1.869E-01	DCF2(3)
B-1	Pa-231	1.280E+00	5.180E-01	8.769E-01	DCF2(4)
B-1	Pu-239	1.900E-01	4.440E-01	4.477E-01	DCF2(5)
B-1	Th-229+D	2.169E+00	9.481E-01	9.865E-01	DCF2(6)
B-1	U-233	1.350E-01	3.552E-02	3.811E-02	DCF2(7)
B-1	U-235+D	1.100E-02	3.145E-02	3.378E-02	DCF2(8)
Dose conversion factors for ingestion, mrem/pCi:					
Menu Code	Parameter	2006 ICRP 72 Value	2017 ICRP 38 Value	2017 ICRP 107 Value	Parameter Name
D-1	Ac-227+D	1.480E-02	4.473E-03	2.308E-03	DCF3(1)
D-1	Am-241	7.400E-04	7.400E-04	8.806E-04	DCF3(2)
D-1	Np-237+D	4.444E-03	4.102E-04	4.674E-04	DCF3(3)
D-1	Pa-231	1.060E-02	2.627E-03	2.068E-03	DCF3(4)
D-1	Pu-239	9.300E-04	9.250E-04	1.066E-03	DCF3(5)
D-1	Th-229+D	4.027E-03	2.269E-03	3.329E-03	DCF3(6)
D-1	U-233	2.890E-04	1.887E-04	2.227E-04	DCF3(7)
D-1	U-235+D	1.713E-04	1.752E-04	2.048E-04	DCF3(8)

Table C-11. RESRAD Dose Conversion Factors (2006 and 2017, U, ADULT)

Dose conversion factors for inhalation, mrem/pCi:					
Menu Code	Parameter	2006 ICRP 72 Value	2017 ICRP 38 Value	2017 ICRP 107 Value	Parameter Name
B-1	Ac-227+D	6.724E+00	2.104E+00	6.714E-01	DCF2(1)
B-1	Pa-231	1.280E+00	5.180E-01	8.769E-01	DCF2(2)
B-1	Pb-210+D	2.320E-02	3.697E-02	4.017E-02	DCF2(3)
B-1	Ra-226+D	8.594E-03	3.526E-02	3.823E-02	DCF2(4)
B-1	Th-230	3.260E-01	3.700E-01	3.848E-01	DCF2(5)
B-1	U-234	1.300E-02	3.478E-02	3.737E-02	DCF2(6)
B-1	U-235+D	1.100E-02	3.145E-02	3.378E-02	DCF2(7)
B-1	U-238	1.060E-02	2.960E-02	3.212E-02	DCF2(8)
B-1	U-238+D	1.063E-02	2.963E-02	3.215E-02	DCF2(9)
Dose conversion factors for ingestion, mrem/pCi:					
Menu Code	Parameter	2006 ICRP 72 Value	2017 ICRP 38 Value	2017 ICRP 107 Value	Parameter Name
D-1	Ac-227+D	1.480E-02	4.473E-03	2.308E-03	DCF3(1)
D-1	Pa-231	1.060E-02	2.627E-03	2.068E-03	DCF3(2)
D-1	Pb-210+D	7.276E-03	6.998E-03	1.026E-02	DCF3(3)
D-1	Ra-226+D	1.321E-03	1.037E-03	1.677E-03	DCF3(4)
D-1	Th-230	5.480E-04	7.770E-04	9.361E-04	DCF3(5)
D-1	U-234	1.800E-04	1.813E-04	2.150E-04	DCF3(6)
D-1	U-235+D	1.713E-04	1.752E-04	2.048E-04	DCF3(7)
D-1	U-238	1.700E-04	1.665E-04	1.939E-04	DCF3(8)
D-1	U-238+D	1.837E-04	1.791E-04	2.112E-04	DCF3(9)

As a result of changes made between the 2006 and 2017 RESRAD calculator versions, with regard to being able to select a child's age in the 2017 calculator version (e.g., infant, 1 yrs old, 5 yrs old, 10 yrs old, 15 yrs old), there were significant differences in the results of the RESRAD-ONSITE runs performed during the review, selecting different ages for each run. Therefore, a comparison of dose conversion factors for non-adults was not performed and is not presented in the tables above.

NOTES

For information not available/provided in the 2006 RESRAD result data sheets, the reviewer used 2017 RESRAD-ONSITE calculator default values.

For Child Surface Soil Am&Pu - Solar Ponds: Revision 7.2 RESRAD-ONSITE internal dose library allows for the selection of an age-range of the child's age (unlike 2006) for use in a given scenario (five non-adult choices of age). The reviewer used "Age 1" as the scenario input for the 2017 recalculation. The "Age" input section is very sensitive to the calculation result, results varied significantly (11.5 to 0.778 mrem) as age selection was varied. The "older" ages (10 & 15) result in relatively smaller doses at time zero (the time of the largest dose to the individual).

The 2006 Child scenarios reviewed identified "child" as the selection, and not "infant." The reviewer followed suit and elected not to use the "infant" option for the Age input selection.

C2.3.6 Dose Assessment Review Results

The dose assessment completed in 2006 used version 6.3 of the RESRAD computer code to calculate radiation doses to a scenario-driven critical population at the Rocky Flats site. The input parameters used in 2006 were entered into the most recent version of RESRAD (version 7.2) to calculate dose. The results of these 2006 calculations were compared to current version of RESRAD (version 7.2) results, allowing the reviewer the ability to compare past RESRAD calculation results to current results. This comparison can then be used to better understand if changes in the results are occurring, and if occurring, to what magnitude. Note that a new dose was not calculated for the Site in this evaluation. No new sample data were collected to support this fourth FYR dose evaluation. Instead, the same input parameters and analytical data values used in 2006 were entered into the most recent RESRAD version to determine the relative impact of changes to the computer code.

In order to understand the relative impact to dose resulting from the numerous changes to input parameters and the computer model that have occurred since 2006, a range of exposure scenarios and associated analytical data evaluated in the 2006 RESRAD (version 6.3) dose assessment were entered into the current RESRAD model (version 7.2). Three existing 2006 scenarios were selected to review and recalculate total dose: (1) resident adult exposure to Pu and Am in subsurface soil in the Ash Pits East area, (2) resident child exposure to Pu and Am in surface soil at the Solar Evaporation Ponds, and (3) WRW exposure to uranium in subsurface soil at the Wind Blown area. This semi-random selection of scenarios was slightly bias-based to include a mix of radionuclides (Am-241, Pu-239, U-234, U-235 and U-238), both adult and child scenarios, three different location sites with surface and subsurface impacts/potential impacts in different OUs. Table C-12 presents the 2006 RESRAD scenario calculation results for the three scenarios, the 2017 RESRAD-ONSITE scenario calculation results using ICRP 38, and the 2017 RESRAD-ONSITE results using ICRP 107.

A comparison of the RESRAD version 6.3 dose results to the RESRAD version 7.2 dose results indicate little change in total dose. Each of the 2006 scenarios evaluated yielded similar results, suggesting that the changes in total dose for all scenarios and locations evaluated in 2006 would be negligible using the current RESRAD model version. This simply means that the changes to RESRAD since 2006 have not resulted in major impacts to dose calculated by the model. That is, the dose calculated using RESRAD version 6.3 is nearly the same as the dose calculated using RESRAD version 7.2, given the same site-specific input parameters used in 2006. Therefore, because the dose assessment from 2006 indicated that the Site is in compliance with the dose criteria ARAR from the CAD/ROD with a total dose much less than 25 mrem/yr, a recalculation of dose using the most updated version of RESRAD would yield the same results and the ARAR would still be met. As a result, this FYR dose assessment evaluation concludes that the dose criteria ARAR continues to be met and the remedy in the COU remains protective.

Table C-12. RESRAD Scenario Calculation Results (2006 and 2017)

RESRAD Scenario Identification	**Maximum Total Dose** (mrem/yr)
2006 Resident Adult Subsurface Soil Am&Pu Ash Pits East	8.918E-04
2017 Resident Adult Subsurface Soil Am&Pu Ash Pits East (ICRP 38)	8.986E-04
2017 Resident Adult Subsurface Soil Am&Pu Ash Pits East (ICRP 107)	9.893E-04
2006 Resident Child Surface Soil Am&Pu Solar Ponds	1.499E+00
2017 Resident Child Surface Soil Am&Pu Solar Ponds (ICRP 38)	1.351E+00
2017 Resident Child Surface Soil Am&Pu Solar Ponds (ICRP 107)	1.361E+00
2006 WRW Subsurface Windblown U	8.499E-03
2017 WRW Subsurface Windblown U (ICRP 38)	8.682E-03
2017 WRW Subsurface Windblown U (ICRP 107)	9.259E-03
2006 WRW Surface Windblown U	8.029E-02
2017 WRW Surface Windblown U (ICRP 38)	8.226E-02
2017 WRW Surface Windblown U (ICRP 107)	8.818E-02

C3.0 POU

[Still needs resolution]

C4.0 OU3

A RCRA Facility Investigation/Remedial Investigation (RFI/RI) report and baseline risk assessment were completed for OU3 in June 1996 (DOE, 1996). This report identified the COCs in OU3 as Pu-239/240 and Am-241 in surface soils and Pu-239/240 in surface sediments within the Great Western Reservoir. Although COCs were only identified for surface soil and sediment in OU3, the RFI/RI gathered and considered a substantial amount of surface water, groundwater, and air data. The baseline risk assessment included evaluation of residential and recreational exposure scenarios. The risk assessment concluded that conditions in OU3 were within the acceptable risk range for protection of human health. The CAD/ROD for OU3 was published in June 1997 and selected no action as the remedy (DOE, EPA, and CDPHE, 1997).

C4.1.1 Radiological Constituents Review Methodology

As with the COU and POU risk evaluations, the 2017 EPA online calculator was used as a basis to generate site-specific PRGs for OU3 that could then be compared to the PRGs from 1994, assuming the same calculator data inputs. No new data were collected for this FYR risk evaluation for OU3. As with the other OUs, in order to perform PRG calculations using the site-specific data from 1994, calculations were performed using Microsoft Excel (instead of the EPA

PRG online calculator). The EPA PRG equations used in the online calculator were written into an Excel spreadsheet calculator and then validated for accuracy. For OU3, the residential scenario was used in the Excel calculator, using values provided in the 1994 *Programmatic Risk Based Preliminary Remediation Goals* document (DOE, 1994).

Figures C-5 and C-6 present the equations use to calculate the PRG for exposure to soil using a residential scenario. As evidenced in these figures and in the resulting comparison of calculated PRGs described later in this section, there have been several changes to input parameters and equations used in the risk assessment since 1994. This presented a challenge when entering the 1994 input parameters into the present-day PRG calculator because some input parameters were not considered in 1994 that are now required input into the EPA PRG calculator.

$$PPRG_i = \frac{TR \times AT \times 365\ days/year}{EF \times \left[(SFi \times IRa \times ED \times \frac{1}{BW} \times \frac{1}{PEF}) + (SFo \times 10^{-6}\ kg/mg \times IF) \right]}$$

where:

Variable	Explanation (Units)	Default Value
$PPRG_i$	Risk-based PPRG for surface soil based on residential use (mg/kg)	-
TR	target excess lifetime cancer risk (unitless)	10^{-6}
AT	averaging time (years)	70 years
EF	exposure frequency (days/year)	350 days/year
SFi	inhalation cancer slope factor $(mg/kg\text{-}day)^{-1}$	COC-Specific
IRa	daily inhalation rate (m^3/day)	20 m^3/day
ED	exposure duration (years)	30 years
BW	adult body weight (kg)	70 kg
PEF	particulate emission factor (m^3/kg)	4.63×10^9 m^3/kg
SFo	oral cancer slope factor $(mg/kg\text{-}day)^{-1}$	COC-Specific
IF	age-adjusted soil ingestion factor (mg-yr/kg-day)	114 mg-yr/kg-day

Figure C-5. 1994 equation for resident soil PRG

Resident Soil

- *Incidental ingestion of soil:*

$$PRG_{res\text{-}soil\text{-}ing}(pCi/g) = \frac{TR \times t_{res}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times SF_s\left(\frac{risk}{pCi}\right) \times IFS_{res\text{-}adj}(1{,}120{,}000\ mg) \times \left(\frac{g}{1000\ mg}\right)}$$

where:

$$IFS_{res\text{-}adj}(1{,}120{,}000\ mg) = \left(\left(EF_{res\text{-}c}\left(\frac{350\ days}{year}\right) \times ED_{res\text{-}c}(6\ years) \times IRS_{res\text{-}c}\left(\frac{200\ mg}{day}\right)\right) + \left(EF_{res\text{-}a}\left(\frac{350\ days}{year}\right) \times ED_{res\text{-}a}(20\ years) \times IRS_{res\text{-}a}\left(\frac{100\ mg}{day}\right)\right)\right)$$

- *Inhalation of particulates emitted from soil:*

$$PRG_{res\text{-}soil\text{-}inh}(pCi/g) = \frac{TR \times t_{res}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times SF_i\left(\frac{risk}{pCi}\right) \times IFA_{res\text{-}adj}\left(161{,}000\ m^3\right) \times \frac{1}{PEF\left(\frac{m^3}{kg}\right)} \times \left(\frac{1000\ g}{kg}\right)}$$

where:

$$IFA_{res\text{-}adj}\left(161{,}000\ m^3\right) = \left(\left(EF_{res\text{-}c}\left(\frac{350\ days}{year}\right) \times ED_{res\text{-}c}(6\ years) \times ET_{res\text{-}c}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_{res\text{-}c}\left(\frac{10\ m^3}{day}\right)\right) + \left(EF_{res\text{-}a}\left(\frac{350\ days}{year}\right) \times ED_{res\text{-}a}(20\ years) \times ET_{res\text{-}a}\left(\frac{24\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times IRA_{res\text{-}a}\left(\frac{20\ m^3}{day}\right)\right)\right)$$

- *External exposure to ionizing radiation:*

$$PRG_{res\text{-}soil\text{-}ext}(pCi/g) = \frac{TR \times t_{res}(year) \times \lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right) \times SF_{ext\text{-}sv}\left(\frac{risk/year}{pCi/g}\right) \times EF_{res}\left(\frac{350\ days}{year}\right) \times \left(\frac{1\ year}{365\ days}\right) \times ED_{res}(26\ years) \times ACF_{ext\text{-}sv} \times \left[\left(ET_{res\text{-}o}\left(\frac{1{,}752\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_{o\text{-}ext\text{-}sv}(1.0)\right) + \left(ET_{res\text{-}i}\left(\frac{16{,}416\ hours}{day}\right) \times \left(\frac{1\ day}{24\ hours}\right) \times GSF_i(0.4) \times GSF_b(1.0)\right)\right]}$$

- consumption of fruits and vegetables back-calculated to soil

$$PRG_{res\text{-}soil\text{-}produce\text{-}ing\text{-}tot}(pCi/g) = \frac{1}{\left(\sum_{i=1}^{n} \frac{1}{PRG_{res\text{-}soil\text{-}produce\text{-}ing}(pCi/g)_i}\right)}$$

where:

n = total number of produce items included

and:

$$PRG_{res\text{-}soil\text{-}produce\text{-}ing}(pCi/g) = \frac{PRG_{res\text{-}produce\text{-}ing}(pCi/g)}{\left(R_{upv}+R_{es}\right)} \times \left(\frac{t_{res}(year)\times\lambda\left(\frac{1}{year}\right)}{\left(1-e^{-\lambda t_{res}}\right)}\right)$$

where:

$$R_{upv} = Bv_{wet} \; ; \; R_{es} = MLF_{produce}$$

- consumption of fruits and vegetables.

$$PRG_{res\text{-}produce\text{-}ing}(pCi/g) = \frac{TR}{SF_f\left(\frac{risk}{pCi}\right)\times IF_{res\text{-}adj}(g)\times CF_{res\text{-}produce}(1)}$$

where:

$$IF_{res\text{-}adj}(g) = \left(\left(EF_{res\text{-}c}\left(\frac{350\ days}{year}\right)\times ED_{res\text{-}c}(6\ years)\times IR_{res\text{-}c}\left(\frac{g}{day}\right)\right)+\left(EF_{res\text{-}a}\left(\frac{350\ days}{year}\right)\times ED_{res\text{-}a}(20\ years)\times IR_{res\text{-}a}\left(\frac{g}{day}\right)\right)\right)$$

- total

$$PRG_{res\text{-}soil\text{-}tot}(pCi/g) = \frac{1}{\frac{1}{PRG_{res\text{-}soil\text{-}ing}}+\frac{1}{PRG_{res\text{-}soil\text{-}inh}}+\frac{1}{PRG_{res\text{-}soil\text{-}ext}}+\frac{1}{PRG_{res\text{-}soil\text{-}produce\text{-}ing\text{-}tot}}}$$

Figure C-6. 2017 equation for resident soil PRG

For example, the 2017 online PRG calculator requires input for each individual element that makes up the overall particulate emission factor (PEF) in order to calculate site-specific PRG values. The calculator does not allow input of a single PEF value, which was the only PEF input parameter available in the 1994 calculations. Figure C-7 shows the PEF screen from the 2017 PRG calculator. Because some of the input data required to use the 2017 online PRG calculator was not in the 1994 dataset, the Excel calculator described in Section C2.3.3, was used. Although default values are available in the 2017 calculator, using default values from 2017 coupled with site-specific values from 1994 would result in a completely different scenario. For the purposes of this FYR risk evaluation, such a comparison would not be meaningful.

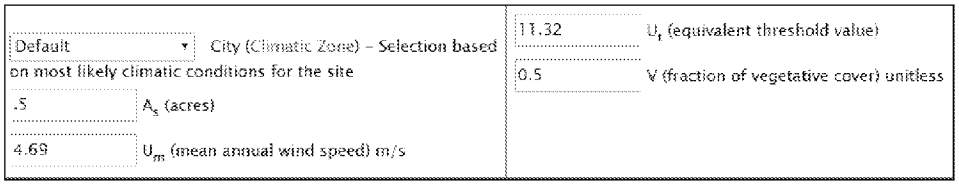

Figure C-7. 2017 Input Required for PEF

C4.1.2 Radionuclide Constituent Evaluation Results

To be able to compare current and previous PRGs from OU3, the 2017 EPA online calculator was used as a basis to generate site-specific PRGs that could then be compared to the PRGs from 1994, assuming the same calculator data inputs for the residential exposure scenario. It should be noted that the 2017 calculations for the resident scenario do not take into account any vegetable consumption from the soil as these data were not included in the 1994 dataset.

Table C-13 presents the OU3 PRGs from 1994 and the Excel Calculator 2017 at a risk level of 1 x 10^{-6} (1 in 1,000,000). As shown in the table, the PRGs are within the acceptable 1 x 10^{-6} risk range, except for U-234 and U-238. The PRG results for U-234 (45.3 pCi/g in 1994; 5.09 pCi/g in 2017) and U-238 (46.0 pCi/g in 1994; 5.63 pCi/g in 2017) changed significantly. In order to understand the level of risk that would result in 2017 PRGs that were comparable to the 1994 PRGs, the risk level in the Excel calculator was raised and the calculation for U-234 and U-238 were re-run using the residential scenario. For U-234 and U-238, a risk level of 9 x 10^{-6} yields PRGs slightly higher than those calculated in 1994. This means that the overall risk from U-234 and U-238 have increased slightly due to changes in toxicity factors and/or calculation methodologies adopted since 1994. For example, if the concentration of U-234 in soil was 45.3 pCi/g in 1994 (equivalent to a 1 x 10^{-6} risk of developing cancer), a similar concentration of U-234 today (45.8 pCi/g) would present a slightly greater risk of 9 x 10^{-6}. This risk is in between a 1 x 10^{-6} risk and a 1 x 10^{-5} (1 in 100,000) risk, but is still within the acceptable risk range allowed by the EPA (1 x 10^{-4} to 1 x 10^{-6}). Based on this risk review, OU3 continues to meet the conditions for UU/UE.

Table C-13. PRGs for OU3 Residential Exposure Scenario (pCi/g at a 1 x 10^{-6} risk level)

Isotope	1994	2017 (using ICRP 107)
Am-241	2.37	3.14
Pu-239	3.43	3.30
U-234	45.3	5.09
U-235	0.17	0.54
U-238	46.0	5.63

Table C-14. Recalculated PRGs for Uranium- 234 and U-238 (pCi/g at a 9 x 10^{-6} risk level)

Isotope	1994	2017 (using ICRP 107)
U-234	45.3	45.8
U-238	46.0	50.7

C5.0 References

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